CO_2 on the International Space Station: An Operations Update

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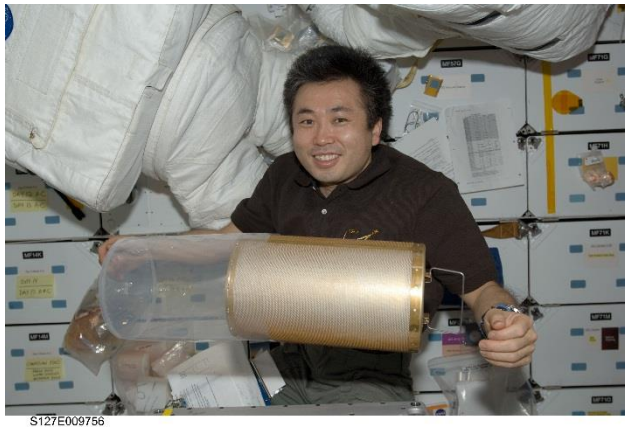
Disclosures

- We have no financial relationships to disclose.
- We will not discuss off-label use or investigational use in this presentation.

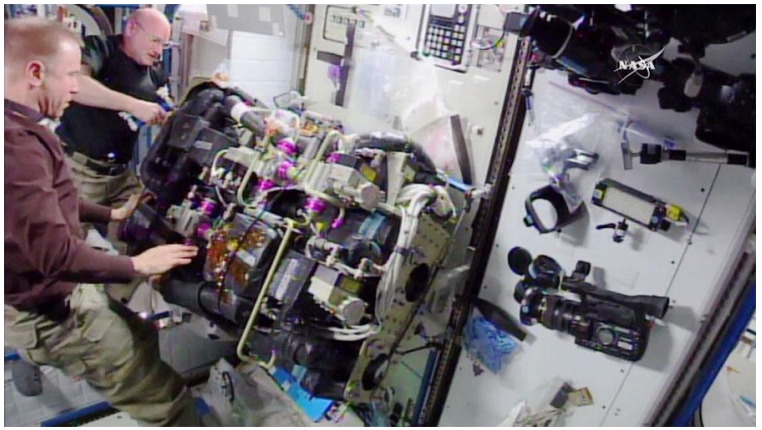
Background

- CO_2 present in Earth's atmosphere at a partial pressure of 0.3 mmHg
- Historically unable to get to terrestrial levels with *regenerable* hardware



Lithium Hydroxide (LiOH) Canisters

- Permanent conversion from Li to Li_2CO_3 (single use)
- Each canister weighs 7 lbs
- Reserved for contingency use
  - 20 canisters would provide 14 days of CO_2 removal for 6 crew



Carbon Dioxide Removal Assembly

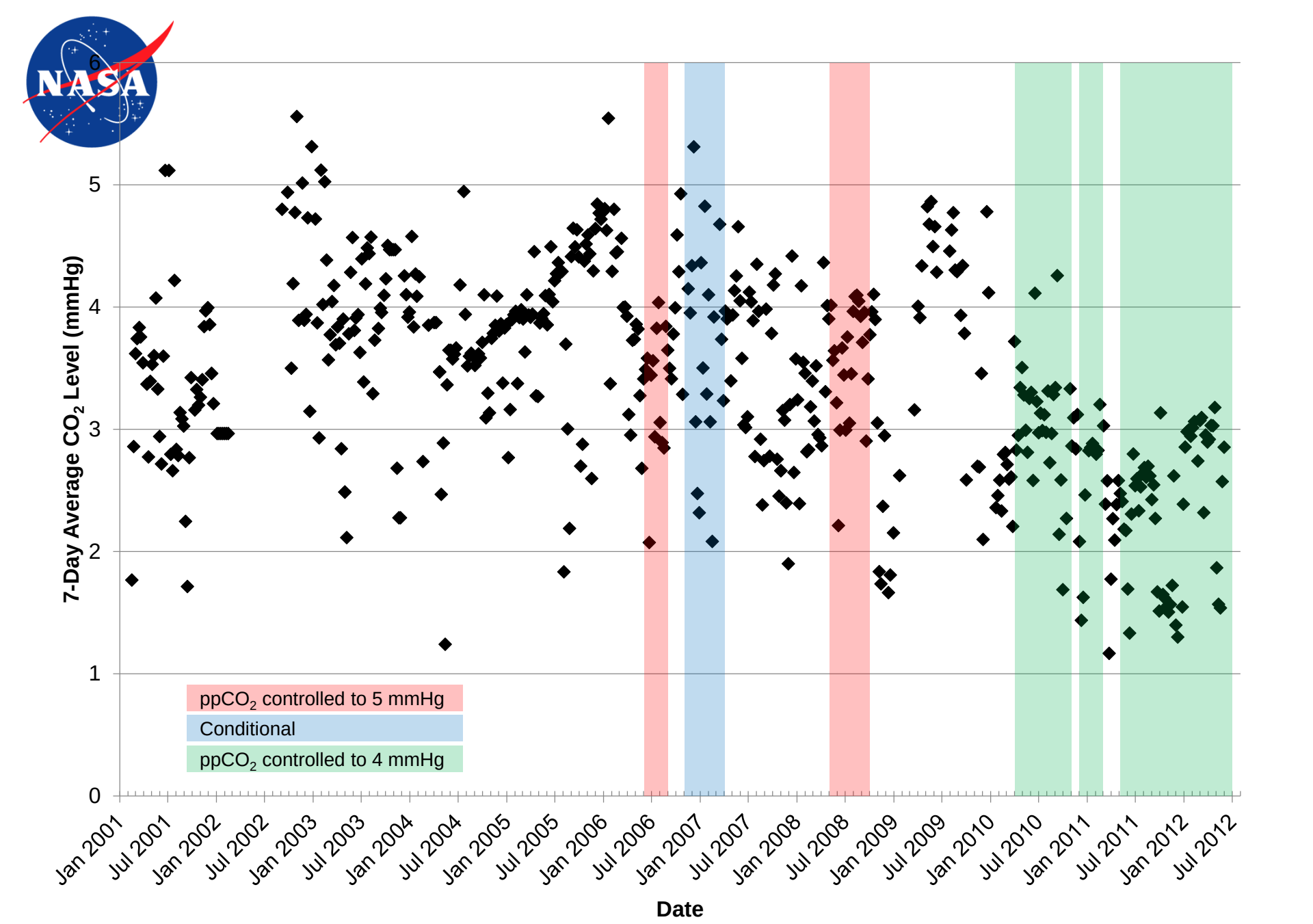
- Regenerable system
- Zeolite desiccant-adsorbent beds
- Typically control $ppCO_2$ to 2-5 mmHg
- Constrained by power, parts, crew time for maintenance

Brief History of CO_2 Control Levels

- Shuttle and original ISS Flight Rule limit for CO_2 was 7.6 mmHg
  - Based on existing terrestrial data
  - Consistent with recommendations set by OSHA and NIOSH in the 1980's
- Throughout ISS program, anecdotal reports have suggested that crewmembers develop CO_2-related symptoms at lower CO_2 levels than would be expected terrestrially
- FR limit revised to 5.3 mmHg in 2008
  - Based on new terrestrial data and the established Space Maximum Allowable Concentration (SMAC) for 7 to 180 days
- Since 2010, operational limits have been driven by crew symptomatology, and Chits have limited the 24-hour average CO_2 to 4.0 mmHg or below.
  - Of note, OSHA and NIOSH have since adjusted their exposure limits to 3.8 mmHg (8-hour TWA) and our interim SMAC value is set at 4.0 mmHg.

CO_2 Symptoms in Spaceflight

- In spaceflight, symptoms seem to occur at lower CO_2 levels than terrestrially
- Reported symptoms include:
  - Fatigue
  - Difficulty concentrating
  - Irritability
  - Performance decrements
  - Headache
    - One of the more easily recognized symptoms
    - Clinically attributed to CO_2 when symptoms are not attributed to another cause and symptoms resolve with lowering of CO_2



Law, et al. Relationship Between CO2 Levels and Reported Headaches on the ISS, JOEM 2014

CO_2 Operational Control Levels: Recent Experience

- We have operated to control limits less than 4 mmHg for portions of 4 out of 6 recent increments
  - Range: 2.7 mmHg (3-hr avg) – 3.4 mmHg (24-hr avg)
- Reports from multiple crewmembers:

CO_2 (mmHg)	Observations
< 2.3	Few reports attributable to CO_2
2.3 - 2.7	Fatigue, full-headedness
2.7 - 3.0	Self-reports of performance decrements, procedure missed steps, procedures going long
> 3.0	Headaches (variable – between 3.0 and 3.4 mmHg) [in addition to the symptoms experienced at lower CO_2]

Notes: Early, semi-quantitative data; range of inter- and intra-individual variability in sensitivity to CO_2

Moving Target…

- Same crewmember
  - One month into mission, denied any CO_2 symptoms when CO_2 peaked at 4.02 mmHg due to Node 3 CDRA failure
  - 2 months later, reported symptoms at 3.5-4 mmHg
    - Two weeks prior, CO_2 elevated due to
      - Back-to-back SPHERES run and METOX regen
      - Node 3 CDRA down

Theories

Why do symptoms occur at lower CO_2 levels in flight than terrestrially?

- Physiologic changes induced by microgravity result in changes to CO_2 sensitivity
- Localized pockets of CO_2 form, allowing crewmembers to be exposed to higher concentrations of CO_2 than are recorded by the MCA
- Individual susceptibility of crewmembers
- Exposure to above-normal CO_2 levels may sensitize some individuals to CO_2 and build tolerance to higher than normal CO_2 in others
- Symptoms develop when there are large or rapid excursions in CO_2 from an established baseline

Conclusion

- There is increasing awareness of CO_2 symptoms by crew and ground teams
- There is mounting evidence that there are health and performance impacts at recent ISS CO_2 levels
  - An operational limit between 0.5 and 2.0 mmHg may maintain health and performance, but data are limited due to hardware
  - 3.0 mmHg is more achievable in the short term – new operational limit since summer 2015
    - May be below the threshold for frank headaches for many crewmembers but still likely to be associated with CO_2 symptoms
- Future work is needed to establish long-term ISS and future vehicle operational limits

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